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Crop production in higher latitude, maritime regions

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III - Wind and air movement

Introduction

Wind, or more generally air motion, exerts a profound influence on plant growth and production - both as a separate element and in conjunction with other meteorological elements.

There are still considerable gaps in our knowledge of how wind interacts with biological processes but enough is now known (much discovered in the past few decades) to make possible a useful assessment of how wind (air motion) aids production in some circumstances and constrains it in others.

A useful first analysis begins with a three category division, viz:-

(1) Gross physical damage: uprooting and "wind-throw" of trees; breakage of tree branches; of stems (of cereals, the shredding and ccnsequential destruction of leaf-tissue (exacerbated if associated with blowing sand and sea spray): damage to growing points of flowers, fruits and seed-cases, loosening of root anchorage.

(2) Morphological effects: evident in influence upon physical structure of the plants or parts of plants e.g. tree shaping and pruning: the deformed and/or stunted growth of much hill and mountain flora.

(3) Anatomical and physiological effects: frequently arising from wind as a component in water and CO_2 exchange processes; on leaf (tissue) temperature.

In the broadest terms, category (1) is associated with high wind speeds (mean and in gusts) gales and generally with events designated in any region as "extreme". In category (2), speeds considerably below gale force are effective - indeed in many regions speeds within the range generally experienced are sufficient to cause these effects. In category (3) interest is generally directed towards the lower speed ranges; wind must be sufficient for a degree of turbulent exchange sufficient to remove the water vapour arising from transpiration and to maintain CO_2 concentrations at all levels within the plant stand, at the normal atmospheric value. Temperature differentials between ambient and tissue temperature may be substantial (of the order of 10°C or more) in zero wind, but these become negligibly small at low ventilation rates.

Some typical speed thresholds relating to these three categories may be of interest.

1. Gross physical damage

This topic is most extensively documented in relation to forestry. Wind throw has been found to depend on the interaction between:-

(i) wind speed and gustiness, snow and ice-loading (if any); shearing-strength of the soil in the rooting-zone (itself partly dependent upon soil moisture and hence rainfall).

and (ii) the size and shape of the tree (i.e. its aerodynamic characteristics) its root depth and anchorage, its position relative to other trees in the stand, whether healthy or diseased.

Fraser (1962a,b) studied, both in a large wind-tunnel and in the open, the turning moment required to uproot a tree and (as an example) quoted that wind with a mean gust speed of 50 knots was sufficient to blow down a mature 60 ft tree.

As a guide to orders of magnitude, severe damage in recent years to mature forests in UK were reported in:-

(i) Scotland (northeast and west) January 1953: gusts 80-100 mph reported frequently in the affected areas (Anderson 1954).

(ii) Northern Ireland September 1961: mean speeds over 60 minutes from 55 to 60 knots and frequent gusts exceeding 90 knots (Woodley 1962).

(iii) Scotland (central) January 1968: mean speeds 55 knots or more sustained for several hours with gust speeds exceeding 90 knots (Neustein 1971).

It has frequently been noted (Hutte 1967, Neustein 1971) that in waterlogged soils the reduction in root anchorage allows wind-blow to arise at considerable lower speeds than quoted above e.g. Hutte states it can be initiated at 15-20 m/s. It is, perhaps, a matter for discussion as to how far the apparent relative absence of wind-throw in (say) Scandinavia is due to absence of strong winds or to such winds occurring only in the winter when tree roots are firmly anchored in the frozen soil. The liability to wind-throw is a function of tree height: in broad terms forestry experience suggests that a stand of trees becomes vulnerable to wind damage when the general tree height exceeds 30 or 60 ft. The relationship between tree height, the critical wind-speed for blow, and the soil type is given by Fraser (1965).

In the British Isles it would appear that severe storm damage to forests is associated with mean speeds (at the standard 10 m above unobstructed terrain) of 50 knots or more and gusts exceeding 90 knots. On any particular occasion, such damage is not countrywise but it would appear at least prudent to anticipate that a forest will be at risk at least once in a particular rotation - whether the consequential damage is serious will depend upon age, height, root anchorage etc of the trees when the gale occurs: (the interaction between gale damage and the economics of forestry are discussed by Wardle (1970)).

Significant damage to commercial farm and orchard crops can occur at speeds much lower than those mentioned above. In appraising these data a useful rule of thumb might be recalled viz that over level unobstructed terrain:-

wind speed at 2 m height 0.78 that at 10 m)
" " " 1 m " 0.50 " " 10 m)

Wind-damage to a range of crops e.g. soft-fruit, top-fruit, flowers etc from battering and bruising requires emphasis. Hogg (1967) quotes a case of severe damage to a bean-crop when mean hourly winds at 10 m ranged between 23 and 33 knots and gusts reported to 50 knots. The height of the plants at the time were of the order of a few tens of cm.

2. Morphological effects

Following the extensive work by Whitehead (e.g. 1964-65 and references) on wind effects on plants, it is convenient to distinguish between:-

(i) gross morphological effects of wind;

and (ii) anatomical effects

Broad associations can be derived between tree shaping (wind-pruning) of trees and shrubs and wind exposure. Clearly stunted and/or unsymmetric growth can arise from a number of causes, but sufficient has now been established to link wind with many features of plant "geometry".

Putnam (1948) identified an association between wind-speed (at specimen height) and various grades of tree deformation: viz, in ascending order:-

(i) "brushing" - when small branches are bent rather like the hair in an animal's pelt

(ii) flagging - branches stretching to leewards

(iii) throwing - main trunk, as well as branches leaning away from the wind

(iv) wind-clipping - leaders suppressed and killed and trees held to a low height

(v) tree-carpet - when no upright growth possible.

For a particular species (balsam) mean wind-speeds at specimen height of between 17 and 27 mph sufficed to cover the range of deformation: Putnam also reported that the most sensitive species encountered were white pine and hemlock; the least balsam and spruce.

Golding and Stodhart (1952) - in their search for windy sites for aero-generators - reported that no suitable sites for a wind-generator were found to carry other than low scrub vegetation and that mean annual wind speeds at heights from about 10 to 30 ft at such sites were at least 15 mph and generally > 20 mph.

Thomas (1958) reviewed work on tree deformation in USA, Japan and Germany and devised a sequence of five categories to apply to the profile of the hawthorn ranging from I no distortions through II "brushing" thence two further stages to V throwing (and equivalent to Putnam category 3). A useful pattern of flow in a Welsh valley emerged from the study of the deformation.

Misawa K, Misawa H (1954 - and mentioned by Thomas) examined the deformation (in some cases defined as but a slight bending of the upper twigs) of a number of species (notably the parsimmon tree) and found these very sensitive to wind, and a good indicator "of the prevailing direction of the seasonal winds in summer". Rice plants however "were bent in response to the prevailing direction of the seasonal winds in autumn, whilst in winter the direction was given by the bending of reeds". Yoskino (1967) undertook an investigation of the same type as Thomas, but in a mountain environment. He found it possible to map exposure zones from tree deformation. However his work provides a further reminder that weather influences other than wind are important and found it necessary to recognise the joint effect of ice and snow, with wind giving rise to an almost complete suppression of branches on the windward side of tree, but <u>without</u> any leaning of the trunk. He suggests that a leaning of the tree trunk is associated with <u>year-round strong</u> winds rather than with seasonal winds.

3. <u>Anatomical and physiological effects of wind</u>

These two aspects are conveniently considered together since, unlike the two previous categories, quite light winds can induce changes.

Some information extracted from Whitehead's papers is relevant at this stage. He reported a sharp decrease in leaf area and internodal length of <u>senecio nebradensis</u> (a groundsel from the mountains of Italy) when wind speed increased from zero to 30 mph. Leaf area fell from 65-80 cm^2 to less than 10 cm^2; plant height from 25 cms or more to 2 cms. His curves, based upon but four speed points (1 mph. 9 mph, 29 mph, 33 mph), showed no obvious discontinuity. In addition Whitehead raised plants of Heliathus from seed to the three internode stage at winds of 1 mph, 9 mph, 19 mph and 33 mph continuous winds; they were then <u>all</u> exposed to a wind of 40 mph the substrate having been brought to field capacity: those raised at 1 mph withered and died in $\frac{1}{2}$ hr, those at 9 mph after an hour, those at 19 mph within some 3 hrs whilst those raised at 33 mph were still alive after the 6 hrs exposure: the symptoms of death were wilting and desiccation. Whitehead relates that the difference between <u>zea mays</u> grown for 40 days at 1 mph wind and 30 mph wind could be summed up as follows - the width of the leaf was increased by 20% and its thickness

by 140%: the numbers of rows of sclerenchyma forming the leaf margin was increased by 400%. He further sums up the phenotypic changes evident with plants in the wind as:

(1) a reduced leaf area

(2) shorter internodes making a more dwarf plant

(3) increase of root relative to shoot

(4) increase of vascular tissue

(5) increase in stomata but decrease in size

(6) reduction in water loss per unit area

and hence

(7) the general development of xeromorphic characters.

A study of particular interest (since the wind-speeds involved were relatively low) is reported by Winter (1964-5). Cauliflower plants were raised in a wind-tunnel at speeds of 0 mph, and 6 mph (measured at crop height and probably equivalent to about 20 mph at the standard 10 m). In these experiments the quite moderate wind "reduced the growth-rate of young plants". Similar contrasts - growth being reduced by wind - were noted in some field experiments devoted to the study of the benefits to lettuce from shelter. "At no time (in either series) was there any gross physical damage." When assessing results such as the above in the context of wind-climate, it is important to recall that wind-speed within a canopy (in a dense crop or forest; below the surface of a vegetative matt) is typically low and hence generally less than the free air speed. In corn (maize) Lemon (1963 p72) gives wind-speed profiles indicating that whilst the above-canopy speeds may be 5 m/s, that a metre or so down from the top of the crop is 1 m/s. Gloyne (1964-5) quotes a number of authorities to the effect that well within a crop stand (forest, cereals, potatoes and scrub vegetation) the wind-speed will exhibit a small variation of a metre/sec or so about a low mean of about 2 m/s. The coupling of this crop wind with the free air wind is loose but positive. As already mentioned, a minimum degree of air movement (ventilation) is however essential for the removal of water vapor and the renewal of CO_2 at the plant leaf surfaces. A few references will suffice. Lemon (1963) discusses CO_2 supply to a tall crop (maize) noting that at low wind speeds (3-4 m/s or less at about $\frac{1}{2}$ m above

the crop) there is insufficient turbulent exchange to meet the photosynthetic demands of lower parts of the stand. Monteith (1964) considers "when the atmosphere is stable and the wind speed near the ground (c. at a height of 2 m) falls below 2 m/s turbulent mixing is much less effective and theory predicts that the concentration may drop to 250 ppm or less at the surface of a crop in bright sunshine".

Turner (1971) in his study of tree growth in sub-alpine regions presents evidence that, at any rate under relatively low levels of solar radiation (250-350 gr cals cm^{-2} day^{-1}), optimal growth is associated with wind speeds (at 1 m above open ground) of about 3 m/s.

Clearly to avoid restriction of CO_2 supply we require a crop ventilation rate of 1 to 2 m/s whilst to eliminate constraints to growth by too much air movement the wind-speed just above the top of the canopy should not exceed say 5 to 6 mph (2 to 3 m/s). The associated speed at the standard height of 10 m is about twice the figure suggesting that the optimal wind-climate for the growth and development of plants is about 5 m/s at the standard height (ie about 10 knots, 11 mph, or 18 km/hr).

(Additional reference for Section 2 - "Morphological Effects")

Birss and Robertson (1970) examined vegetation at many sites in Scotland and derived the 5 categories mentioned below. They also, using such information as was available from standard stations, assessed a value of the associated mean annual wind-speed. The resulting classification was as under:

Category	Vegetation effect	Mean annual wind-speed
Sheltered:	excellent tree growth	2 m/s
Moderately exposed:	moderate " "	2.6 to 4.4 m/s
Exposed:	poor " "	4.4 to 6.2 m/s
Very exposed:	very short heather	6.2 to 8.0 m/s
Extremely exposed:	zero or prostrate heather	8 m/s

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